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Toward Pull Remanufacturing: a Case Study on Material and Information Flow Uncertainties at a German Engine Remanufacturer

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Abstract

Together with reuse and material recycling, remanufacturing has emerged as a sustainable approach for used products. Remanufacturing is more complex than manufacturing, due to the uncertainties in material and information flows inside the remanufacturing facility and along the product life-cycle. Therefore, some remanufacturers intend to use lean production principles and philosophies to deal with this complexity and to improve their operations.

The aim of this paper is to identify reasons for possible material and information flow uncertainties and develop lean-inspired solution at a German engine remanufacturer. The empirical data were collected via a Material and Information Flow Analysis workshop. The reasons for missing, late, defective and non-available spare parts as well as disrupted, uneven, chaotic and inaccessible information flows are identified. Finally, a lean pull Kanban reordering system is suggested and recognized to be a proper solution to remanufacturing complexity.

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1. Introduction

Together with reuse and recycling, remanufacturing has emerged as a sustainable approach to prolong the life of used and worn-out products. Whilst being the most environment-friendly and profitable product recovery option, remanufacturing often consists of several steps, e.g. inspection, cleaning, disassembly, testing, reprocessing and reassembly [1, 2].

According to recent research, remanufacturers struggle to deliver quick and efficient end-of-life solutions and perform below their potential. The remanufacturing process is typically more complex than manufacturing, due to the uncertainties in material and information flows inside the facility and through the whole product life-cycle [3]. Lean production management strategy, inspired by the Toyota Production System (TPS), proved to be successful in solving

operational challenges in process, people, product, profit and performance improvement [4, 5].

A great potential for applying lean production principles and philosophies (Lean) to remanufacturing has been noted by several researchers and can be further read about in Kurilova-Palisaitiene and Sundin [6]. According to Sundin [2], lean production concepts are beneficial for remanufacturing since they enable *lowering the inventory and work in process (WIP) levels and improving material movements, product flow and use of space*. The findings of Fargher [7], Jacobs et al. [8], Östlin and Ekholm [9], Hunter and Black [10] and Kucher [11] show that Lean helps remanufacturers to decrease lead time and costs, increase productivity, enhance quality, make a continuous flow and create value in every process. Therefore, some remanufacturers intend to use Lean to improve their operations and reduce uncertainty in material and information flows.

2. Aim

The aim of this paper is to identify the reasons for possible material and information uncertainties and develop lean-inspired solution at a German engine remanufacturer.

3. Data collection method

Data were collected via a Minimum time for Material and Information Flows analysis (MiniMifa) workshop at a German engine remanufacturer. The MiniMifa workshop is designed to discover remanufacturing challenges and improvement opportunities expressed by MiniMifa participants - company's employees, involved in daily remanufacturing operations [12].

During the MiniMifa workshop, 5 to 6 participants develop a remanufacturing process map on a large piece of paper using simple tools, like pencils and post-it notes, similar to the Value Stream Mapping (VSM) method (see Fig. 1) [13]. One remanufactured product is selected and the path it moves on is studied, from one involved actor (department/function) to another and from one process step to the next. In line with following the material/product (cores, spare parts) flow, the information on that particular product's routes is studied. By following material and information flows along the remanufacturing process and beyond the factory borders, a complete picture of the remanufacturing process is constructed.



Fig. 1: Map of MiniMifa at the German engine remanufacturer.

The MiniMifa workshop delivers a map of the remanufacturing process with the main remanufacturing operations, organizations, functions and people involved in the process, and quantitative as well as time characteristics. Moreover, the challenges of current material and information flows with possible improvement initiatives are plotted directly on the map. This visual representation of the remanufacturing process is constructed via a dialog with remanufacturing employees working in different departments/functions.

The MiniMifa workshop implies an in-depth analysis of the material and information flows and the challenges that prohibit smooth and efficient circulation. After challenges are collected the improvements' initiatives are developed and prioritized. The ease of implementation and the degree of material and information flow improvements are two criteria that determine which Lean techniques will be applied to the German engine remanufacturer.

4. Company background

In the 1970s and 1980s there were no facilities to remanufacture cars in Germany; moreover, only expensive brand-new spare parts were available on the market. High spare part price implied a complex part acquisition process in Japan, as well as expensive logistics activities and time-consuming storage in German warehouses. The German engine remanufacturer studied used to acquire new spare parts at the same time as the new cars were ordered and transported to Europe. The additional price for spare parts covered the logistics, storage for 3 to 10 years and other additional costs until the spare parts were sold.

Remanufacturing has now solved this problem. Today, selling remanufactured spare parts is profitable. At the same time, remanufacturing fulfils the needs of environment-friendly customers as well as their need for paying a lower price for their car service. In comparison with the new part at 100% cost, the remanufactured part only costs 55% to 65% of that. The same quality is assured through the same warranty conditions. Hence, it makes less sense for end customers to buy a brand new part. Therefore, today's remanufacturing facilities keep expanding. Simultaneously, competition with brand new spare parts is increasing in some markets. However, when the serial production of brand new parts stops, remanufacturers take over an available market since the remanufactured parts replace new parts.

5. Remanufacturing process

The German engine remanufacturer studied is a contracted remanufacturer with the Original Equipment Manufacturer (OEM) for 100 parts at a time. The remanufacturing contract (reman-contract) conditions imply no investments in core acquisition and pre-determined amounts of core demand and supply, while the OEM is a supplier of spare parts [14, 15]). The forecasted monthly demand is for 40 remanufactured engines. The OEM places an order to remanufacture an engine when the final customer wants to replace a broken or worn-out one. However, the supply-demand balance is threatened when the returned engines are not possible to remanufacture. The challenges in core quantity, quality and timing [2] are not relevant to the studied company due to the reman-contract condition. However, the challenges of spare part acquisition disturb the remanufacturing business by causing irregular and unpredictable flows of material and information in the remanufacturing facility and the whole product life-cycle.

When the collected core arrives at the warehouse the sales or product planning team informs the warehouse manager, who gives the command to start remanufacturing. A typical engine remanufacturing process is depicted in Fig. 2.

From the warehouse, the cores are processed for dismantling, where the quality is checked, pictures are taken of the defects, and the damages are documented. There, the core is disassembled into four master parts. Each of the parts follows its own route through cleaning and remanufacturing until they meet at the assembly of the short block. Finally, the spare parts are joined with the short block in a second

assembly. When the remanufacturing process is finished and the engine is ready to be sent, the batches of eight engines are delivered to the OEM. A typical time for each remanufacturing process step as well as the waiting time between the operations and for the spare parts is represented in Fig. 2 and Fig. 3.

The remanufacturing process can take from one week (best case) up to 13 weeks (worst case). A large distribution in lead time is often a result of irregular material and information flows that cause some non-value-added activities, such as waiting for a driver, waiting to start an order, waiting for standard spare parts, transportation between processes, and waiting for a special spare part. If all these wastes are eliminated or reduced and controlled, the process lead time can become much shorter and more predictable.

5.1 Information Flow

Disrupted, uneven, chaotic and inaccessible information between remanufacturing processes, operations and product life-cycle actors is a big challenge for the German engine remanufacturer.

The largest remanufacturing challenge, disclosed during the MiniMifa workshop, was the **waiting time for special parts**. This time accounts for at least 85% of the lead time in the worst case (see Fig. 3). Nevertheless, the **waiting time for standard parts** contributes with a relatively small portion of non-value added time, however it occurs much more often compared with the waiting time for special parts.

Dealing with remanufacturing challenges is associated with **daily troubleshooting**. **Information deficit** of the remanufactured spare parts' quality, quantity and timing

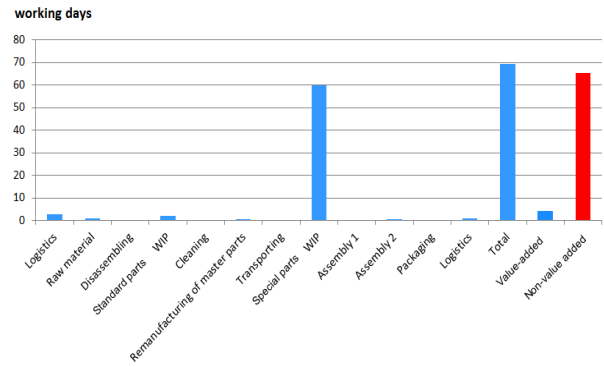


Fig. 3: Lead time at the German engine remanufacturer.

suspends a long-term business approach.

The Production Manager (PM) describes this daily troubleshooting as: “*sending information back and forth between the process steps. If in the disassembly area some engines are damaged, cracked or broken, the information is given to the workshop/warehouse managers. They inform the sales department about the need for more cores - engine blocks - consequently sales contacts the customer.*”

The remanufacturing Technical Manager (TM) adds that the daily troubleshooting prolongs the remanufacturing process. He mentions that “*today one person has information and it is locked in this head and he did not offer it to several other people to make sure we can go on with the project.*” The Quality Manager (QM) agrees and elaborates that “*some problems can be solved in big groups. In this company people try to solve the problem alone.*” Their desire is to remanufacture engines in a shorter time and with high quality, while keeping information open, accessible and updated.

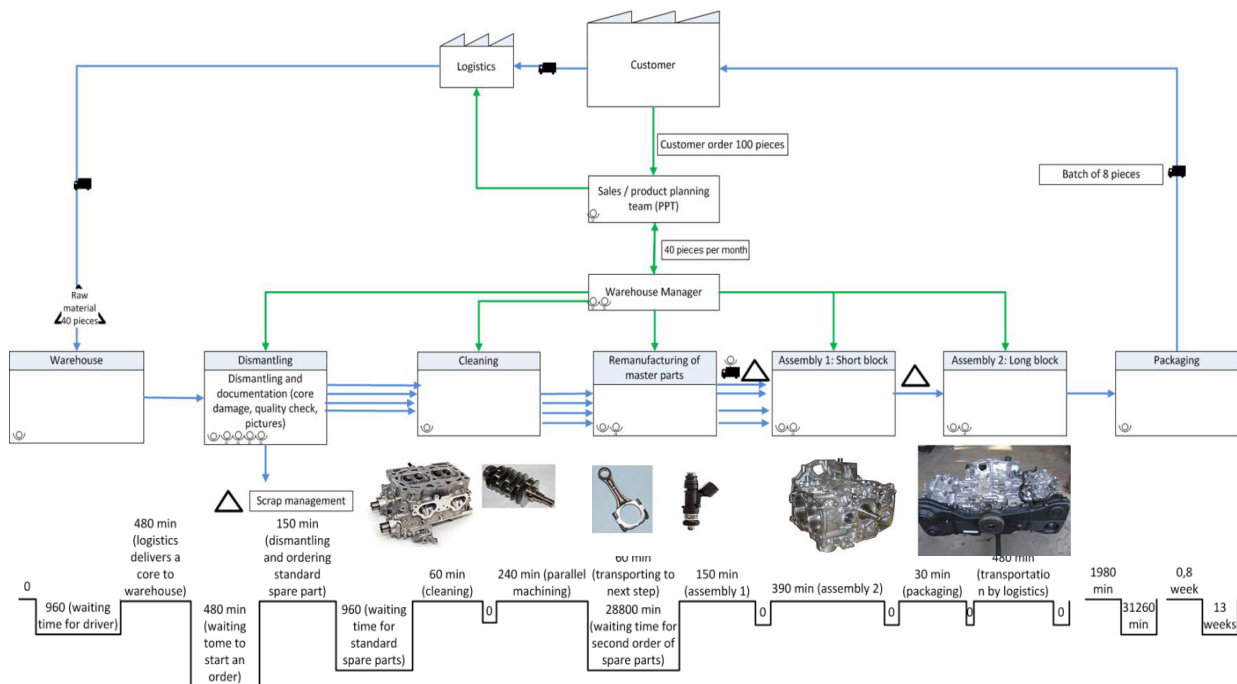


Fig. 2: Generic remanufacturing process at the German engine remanufacturer with value-added and non-value added activities (the value-added activities are placed on the line, while the non-value added are in the “pockets”)

5.2 Information feed-forward

The PM stated that there is **no information feed-forward**, which means that the remanufacturer must search for a possible source of information. The PM also mentioned that in the beginning of remanufacturing activities, no one in the product life-cycle shared information. He claims that: *“if you ask for a homing process or specifications, for example, on a cylinder head, you will not get this kind of information”*. The OEM decides if the remanufacturer can perform the remanufacturing on OEM's products and only then offers *“some kinds of secrets”*. Today, the remanufacturer asks for information from the OEM. Sometimes it is possible to get a partner who supplies brand new parts in the same region. Often, the remanufacturer buys a new engine to study its structure in order to create knowledge for remanufacturing.

The PM revealed that the company did not know anything about the remanufacturing process. He continued that the remanufacturer has to establish the product knowledge itself. The remanufacturer inspects and decides whether the engine can be used the second time. It is the remanufacturer's decision to determine if it is feasible to remanufacture an engine with small cracks; the engine must also be good enough for 2,000 km more.

5.3 Material flow

Missing, late, defective and non-available spare parts are other big challenges for the German engine remanufacturer.

According to the TM, the remanufacturer performs all process steps as manufacturer as well as additional process steps like disassembling, cleaning and checking (see also [16]). This makes the remanufacturing process complex and much longer. The main problem with process time is **delays in each process step**, for example when something is wrong or some spare parts are not delivered on time. The remanufacturer does not measure the process time and has no standard process/lead time established. Every employee does remanufacturing **operations in different times**, depending on the employees' qualifications and experience as well as the quality of the core and spare parts. This is the conflict between the quality of the remanufactured products and the efficiency of the remanufacturing process.

The studied remanufacturer classifies products according to well, good or bad conditions and scrap, where core availability and established remanufacturing knowledge are two determinant factors. While receiving enough cores, **spare parts cause major difficulties**. The delivered cores are self-controlled according to the established quality management system requirements.

The first quality gate is to inspect the parts after the cleaning process. At this step the vital decision - to remanufacture the core or not - is made. The remanufacturer does not perform a hot or a cold test on the engine; the remanufacturing operator can only visually check the condition of an engine, turn it on to see the oil pressure and listen to some noise. Besides, a more intensive, detailed and time-consuming test is not forced by a customer. According to the PM, it is a big challenge to guarantee that the

remanufacturing operations are performed by well-trained employees. Typically, the remanufacturer investigates how to improve remanufacturing, or how to collect more spare parts from disassembled cores and scrap from the parts.

Furthermore, the remanufacturer is dependent on the spare parts supplier - the OEM. According to the PM, no spare parts equals no business for remanufacturing. He describes: *“If the cores are available in high volume you can decide to disassemble them and build another one. If an engine's spare part is missing - this is the end. The distance to the OEM is great. The remanufacturer does not talk to the OEM; this is the main problem.”* He adds: *“We wait for spare parts. You order them, there is no or little information back if the spare parts are available, and it is like a bag and you wonder what is inside. You open it and you are happy or unlucky.”*

Today, remanufacturers do not know in advance what is in that *“bag”*, e.g. if the right part in the right dimension is delivered. Moreover, some parts are poorly packed and are delivered damaged. The PM explains: *“when a package reaches us, some kinds of bearings are wrapped and placed in a box; some are sent in a bag and damaged or destroyed; some have the wrong dimensions; and some are rusty. Last year we received an engine with seven short screws and seven long screws. One long screw is 11 mm, the rest are 12 mm. We tried to perform the second process step and the brand new part was cracked because of that different 11 mm screw. So this core is still standing in our workshop and we had to buy it from a customer.”*

6. Suggesting a Pull Kanban reordering system to Information and Material flows management

To tie Information and Material Flows together into a well-functioning and efficient system, a pull Kanban reordering system was suggested.

According to Hopp and Spearman [17], in contrast to push, pull production is recognized for controlled and limited WIP. Kanban, which consists of cards as a triggering mechanism that authorizes a certain production task to be performed [18], is one of the most popular job reordering systems.

According to Gonzalez, Framinan and Pierreval [18] there are at least 18 different types of reordering systems like Kanban. Kanikula and Koch [19] developed nine Kanban replenishment scenarios including inventory management, pull system and controlled buffer in remanufacturing. Different production control systems are designed considering external and internal conditions for system performance: customer behavior (constant vs. stochastic demand), availability of raw material (infinite availability or not) and correspondingly shop floor operating conditions (distribution of processing time, breakdowns, reworking and set-up times).

Remanufacturing is different from manufacturing with respect to WIP. Remanufacturing companies deal with much smaller batches and higher product variation [5]. Compared with serial manufacturing, remanufacturing cannot operate owning small quantities of cores and spare parts on-site. This implies a stricter control of acquired cores and spare parts. However, the minimum and maximum level of inventory has to be defined. In the case of the German engine remanufacturer, the portion of spare parts and WIP will

increase. Nevertheless, the costs for holding it in the controlled buffers will not increase dramatically, since the majority of items are cheap. As stated by a MiniMifa participant: “You can get hills of material that do not cost you anything. And if you have a production of 100 engines you can have a temporary buffer of 20 engines without any problem.” With a pull reordering system, the remanufacturer would be able to solve long lead times as well as quality and information problems, and there would be only one, not six (six departments), information flows.

Therefore, the pull Kanban system is focused on stabilizing the remanufacturing process, optimizing the process steps, improving cooperation with customers and suppliers, and improving both information and material flows in remanufacturing as well as in the whole product life-cycle.

The Kanban system implies close and open cooperation with OEM. Therefore, Kanban for the supply chain is an integral part of the proposed Kanban system (see also [20]). However, in order to keep the discussion simple only Kanban for the remanufacturing facility is demonstrated. Open information on product characteristics, design, maintenance/service history, and the condition of incoming cores could improve the remanufacturing process [1, 21]. Feeding forward the product information from all involved product life-cycle actors would improve a sustainable loop solution and enable remanufacturing to deliver better results.

Fig. 4 represents the possible pilot transformation toward lean – as a best buffer and not low buffer remanufacturing system [17]. A simplified working principle follows the discussed Kanban system, when demand information goes in another direction than material. Information from sales reaches a warehouse manager, who gives a command to assemble a long block. The long block spare parts, including the short block, are withdrawn from the parts buffer in front of *Assembly 2*. This is the signal for operators in *Assembly 1*

to collect parts from the remanufacturing of master parts and start their operations. Simultaneously, external spare parts are collected from the supplier. This is the non-stop process of withdrawal of spare parts until the disassembly process step. In disassembly the cores are dismantled and controlled, sorted or scraped. This is to stock remanufacturing and is similar to push production, which is usually based on a fixed forecast. Since today remanufacturing has very little or no power to influence a supplier, it cannot determine the quantity and quality as well as timing of spare parts [2, 5]. In the future, when the total product life-cycle will be integrated in a sustainable symbiosis with open and shared information and material flow, the new investigation of ordering system will be performed.

Additionally, an analysis of value and non-value added time collected during the MiniMifa workshop discovered the potential to save up to three weeks in lead time, which corresponds to a 69% lead time reduction (compare Fig. 2 and Fig. 4).

7. Discussion

During the MiniMifa workshop, participants surprisingly discovered that *17 people are remanufacturing one engine in three months*. The problem is communication, because the production planner has to communicate with six departments; this takes a long time and certain information ends up missing. With the help of the MiniMifas map, for the first time the remanufacturer could look at the remanufacturing processes and its problems plotted on a large piece of paper. Based on the feedback from workshop participants MiniMifa can be further developed and used as a helpful diagnostic tool for material and information flows’ challenges in other industries as well.

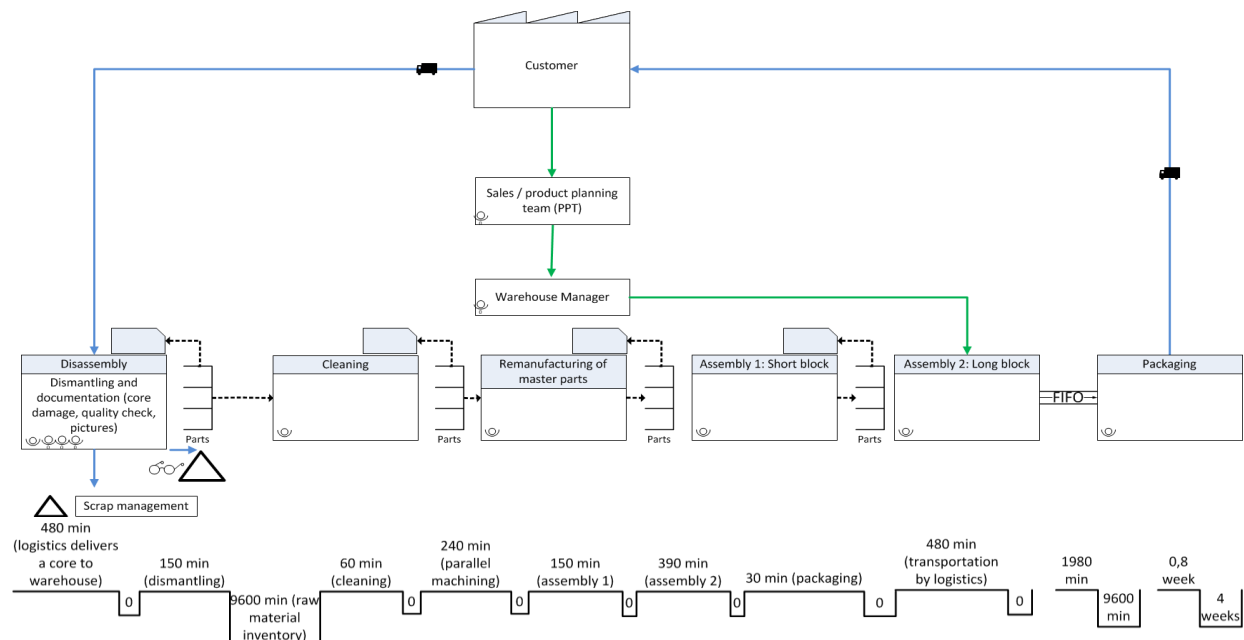


Fig. 4: Possible pilot transformation toward lean with a pull Kanban reordering system and non-value added and value-added process time.

8. Conclusions

The design and execution of the MiniMifa workshop satisfied the need to study remanufacturing material and information flows. The delivered results are a map with material and information flow challenges, value-added and non-value added activities, and possible lean improvements.

During the MiniMifa workshop the **reasons** for uncertainties in material and information flows at a German engine remanufacturer were identified:

- **Quality, quantity, timing** of special and standard **spare parts**
- **Poor communication** and an **information deficit** about the status of spare parts
- **No feed-forward information** between product life-cycle actors and remanufacturer
- **Delays in each process step** associated with different operators' process time and deviations to agreed delivery times for the right spare part

These are the reasons for missing, late, defective and non-available spare parts and disrupted, uneven, chaotic and inaccessible information flow. Moreover, it was discovered that the remanufacturer is dependent on the spare part supplier – the OEM. Daily troubleshooting is a typical short-term solution to deal with these challenges.

The **lean-inspired solution** was developed to tie information and material flows together into a well-functioning and efficient system. A **pull Kanban reordering system** was suggested and accepted as a proper solution to the remanufacturer's uncertainties in material and information flows. A possible pilot transformation toward lean – as a best buffer and not low buffer production system – was presented. This system was designed considering reman-contract conditions: customer behavior, availability of cores and spare parts, and shop floor operating conditions.

The remanufacturing pull Kanban system is focused on stabilizing the remanufacturing process, optimizing the process steps, improving the cooperation with customers and suppliers, and improving both information and material flows in remanufacturing as well as in the whole product life-cycle. The analysis of the proposed reordering system discovered the possible savings in lead time of up to three weeks, which corresponds to a **69% lead time reduction**. Based on an analysis of deliverables from the MiniMifa workshop, it is recommended to consider pull Kanban system implementation. The pull Kanban system would lead to a further Lean application at the German engine remanufacturer.

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